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# CPUE standardization of blue marlin (*Makaira mazara*) caught by Taiwanese longline fishery in the Indian Ocean

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## ABSTRACT

This study provided a CPUE standardization of blue marlin (*Makaira mazara*) caught by the Taiwanese longline fishery in the Indian Ocean for time periods of 1980-2011 and 1995-2011. The delta-lognormal GLM model is adopted to perform the CPUE standardization analysis since blue marlin is caught by Taiwanese longline fleet as bycatch species and large amount of zero catches are recorded in the operational data sets. The results indicate that the influence of incorporating environmental effects on CPUE standardization is not significant for blue marlin in the Indian Ocean. The trends of CPUEs in Area 1 (MONS) and Area 3 (Coastal area) revealed substantial decline trends before early 1990s and increased until later 1990s, while the CPUE in Area 2 (ISSG) continuously increased before 1995s. The CPUEs slightly increased before 1998 and 2002 for Area 1 and Area 2 respectively, revealed decreasing patterns until 2008, and they sharply increase in recent years. However, the trend of CPUE in Area 3 obviously increased before 1999 but the continuously decreased thereafter. The area-aggregated CPUE generally reveals a trend for five phases: fluctuated before 1986, sharply decreased during 1986-1990 when the catch began increasing; increased gradually during during1991-1999; decrease gradually during 2000-2007; CPUE obviously increased in recent years.

## 1. INTRODUCTION

Based on the report of IOTC WPB (IOTC, 2012), blue marlin are considered to be bycatch of industrial and artisanal fisheries. Blue marlin are caught mainly under drifting longlines (60%) and gillnets (30%) with remaining catches recorded under troll and hand lines, and the fleets of Taiwan (longline), Indonesia (longline), Sri

Lanka (gillnet) and India (gillnet) are attributed with the highest catches of blue marlin in recent years. The catches of blue marlin under drifting longlines were more or less stable until the mid-1980's, and steadily increasing since then. The largest catches were recorded in 1997.

After 1994, the data of catch and effort with 1-degree resolution and the information of number of hooks between float (NHBF) began to be available. In addition to explore the pattern of relative abundance of blue marlin in the Indian Ocean for time series from 1980 to 2011, this paper also attempt to the standardize CPUE of blue marlin caught by Taiwanese longline fleet in the Indian Ocean for the period of 1995 to 2011. Since blue marlin are bycatch species of Taiwanese lognline fleet, large amount of zero-catches are recorded from Taiwanese longline fleet. The annual proportions of zero-catch were about 55%, while the proportions of zero catch decreased in recent years (Fig. 1). Historically, ignoring zero observations or replacing them by a constant was the most common approach. Currently, the most popular way to deal with zeros is through the delta approach (Maunder and Punt, 2004). Therefore, the delta-lognormal GLM (Pennington, 1983; Lo et. al., 1992; Pennington, 1996) is applied to standardize the CPUE in this study.

## 2. MATERIALS AND METHODS

### 2.1. Catch and Effort data

In this study, daily set-by-set catch and effort data (logbook) of Taiwanese longline fishery with 5x5 degree grid for 1980-2011 and 1x1 degree grid for 1995-2011 are provided by Oversea Fisheries Development Council of Taiwan (OFDC). In order to reduce the variability of catch condition of blue marlin for each vessel, the catch and effort data are aggregated to be monthly operational set by set data, i.e. aggregated by year, month, vessel scale (ton-degree), longitude, latitude and NHBF.

### 2.2. Definition of fishing areas

Based on the comments of IOTC (2012), the ecological geographic areas in the Indian Ocean are adopted as the factor of fishing area for the CPUE standardization (Fig. 2). Area 1 is the Indian Monsoon Gyres Province (MONS); Area 2 is the Indian South Subtropical Gyre Province (ISSG); Area 3 is the Indian Ocean Coastal Biome.

### 2.3. Environmental data

The details of environmental data used in this study were described in the paper of Nishida et al. (2012).

## 2.4. CPUE Standardization

The delta-lognormal GLM is applied to standardize the CPUE in this study and the main effects considered in this analysis are year, month, area, vessel scale and NHBF.

The environmental effects included in the model are sheer currents (SC), thermocline depth (TD), and temperature at depth of 55m (T55) and temperature gradient at depth of 55m (TG55). Although the some environmental effects (e.g. TD, and TG55) likely reveal nonlinear relationship with CPUE and might be considered as categorical effects (Wang and Nishida, 2013), all of environmental effects are still treated as continuous variables for simplifying the model. The time-lags of environmental effects on the CPUE are also taken into account in the model. We linked the time series of CPUE data together with the environmental effects based on the time-lags calculated by Wang and Nishida (2013).

The effect of number of hooks between float (NHBF) are treated as three categories (regular: <=9 hooks; deep: 10-14 hooks; ultra deep: >=15 hooks) (Wang and Nishida, 2011).

As discussions during the meeting of the Working Party on Billfish in 2013, the CPUE standardization analysis is suggested to be carried out based on the data for entire time series of 1980-2011. The CPUEs of bigeye tuna and albacore characterized into 3 categories are incorporated as targeting effects because NHBF is only available after 1994 (Wang et al., 2012). In addition, environmental effects are not considered to be used in the CPUE standardization.

Hinton and Maunder (2004) indicated that interactions with the year effect would invalidate the year effect as an index of abundance. The interactions between environmental effects not considered into the model because there may be high autocorrelation would occur among environmental effects. In addition, vessels with different scales were not operated in entire Indian Ocean for every month and thus the interactions with vessel scale are not considered in the model. For the interactions between effects, therefore, the interactions between the effects of year and area and between the effects of month, area and NHBF are considered in the GLM. The delta and lognormal models are conducted as follows:

Lognormal model for CPUE of positive catch for 1995-2011:

$$\log(CPUE) = \mu + Y + M + A + CT + NHBF \\ + TD + T55 + TG55 + SC + \text{interactions} + \varepsilon^{\log}$$

Lognormal model for CPUE of positive catch for 1980-2011:

$$\log(CPUE) = \mu + Y + M + A + CT + T\_ALB + T\_BET + \text{interactions} + \varepsilon^{\log}$$

Delta model for presence and absence of positive catch for 1995-2011:

$$\begin{aligned} PA = \mu + Y + M + A + CT + NHBF \\ + TD + T55 + TG55 + SC + \text{interactions} + \varepsilon^{del} \end{aligned}$$

Delta model for presence and absence of positive catch for 1980-2011:

$$PA = \mu + Y + M + A + CT + T\_ALB + T\_BET + \text{interactions} + \varepsilon^{del}$$

| | | |
|---|---|---|
| where | *CPUE* | is the nominal CPUE of positive catch of blue marlin (catch in number/1,000 hooks), |
| | PA | is the nominal presence and absence of positive catch, |
| | $\mu$ | is the intercept, |
| | *Y* | is the effect of year, |
| | *M* | is the effect of month, |
| | *A* | is the effect of fishing area, |
| | *CT* | is the effect of vessel scale, |
| | *NHBF* | is the effect of number of hooks between float, |
| | *T_BET* | is the effect of the CPUE of bigeye tuna, |
| | *T_ALB* | is the effect of the CPUE of albacore tuna, |
| | *TD* | are the environmental effects of thermocline depth, |
| | *T55* | are the environmental effects of temperature at depth of 55m, |
| | *TG55* | are the environmental effects of temperature gradient at depth of 55m, |
| | *SC* | are the environmental effects of sheer currents, |
| | $\varepsilon^{log}$ | is the error term, $\varepsilon^{log} \sim N(0, \sigma^2)$, |
| | $\varepsilon^{del}$ | is the error term, $\varepsilon^{del} \sim Bin(n, p)$. |

The area-specific standardized CPUE trends are estimated based on the exponentiations of the adjust means of the interaction between year and area effects (Butterworth, 1996; Maunder and Punt, 2004).

The standardized relative abundance index is calculated by the product of the standardized CPUE of positive catches and the standardized probability of positive catches:

$$index = e^{\log(CPUE)} \times \left( \frac{e^P}{1+e^P} \right)$$

## 2.5. Adjustment by area size

The estimation of annual nominal and standardized CPUE is calculated from the weighted average of the area indices (Punt et al., 2000).

$$U_y = \sum_a S_a U_{y,a}$$

Where $U_y$ is CPUE for year *y*,

$U_{y,a}$ is CPUE for year *y* and area *a*,

$S_a$ is the relative size of the area *a* to the four new areas.

The relative sizes of fishing areas are calculated by GIS software and the relative sizes are listed below.

| Area 1 | Area 2 | Area 3 |
|---|---|---|
| 0.297 | 0.429 | 0.274 |

# 3. RESULTS AND DISCUSSION

Based on the lognormal model selection for 1995 to 2011, all main effects and interactions are statistically significant. The selected lognormal model is:

$$\log(CPUE) = \mu + Y + M + A + CT + NHBF + TD + T55 + TG55 + SC$$
$$+ Y * A + M * A + M * NHBF + A * NHBF$$

The ANOVA table of the selected lognormal model is shown in the Table 1. The results indicate that the main effect of area is the most significant effect for the model and the secondarily significant main effect is the effect of T55. The distribution of residuals adequately conforms to the assumption of normal distribution (Fig. 3).

Based on the delta model selection for 1995 to 2011, only the interaction of A*NHBF is excluded from the delta model since this effect is not statistically significant. The selected delta model is:

$$PA = \mu + Y + M + A + CT + NHBF + TD + T55 + TG55 + SC \\ + Y*A + M*A + M*NHBF$$

The ANOVA table of the selected delta model is shown in the Table 2. The most explanatory main effects for the mode are the effects of T55 and area and the secondary is the main effect of TD.

We also examined the CPUE standardizations based on the data from 1995 to 2011without environmental effects. For the lognormal model, all main effects and interactions are statistically significant. The selected lognormal model is:

$$\log(CPUE) = \mu + Y + M + A + CT + NHBF \\ + Y*A + M*A + M*NHBF + A*NHBF$$

The ANOVA table of the selected lognormal model is shown in the Table 3. The results indicate that the main effect of area is the most significant effect for the model. Except for the effect of year, the secondarily significant main effects are the effects of month and NHBF. The distribution of residuals adequately conforms to the assumption of normal distribution (Fig. 4).

For the delta model selection without environmental effects for 1995 to 2011, all main effects and interactions are also statistically significant. The selected lognormal model is:

$$PA = \mu + Y + M + A + CT + NHBF \\ + Y*A + M*A + M*NHBF + A*NHBF$$

The ANOVA table of the selected delta model is shown in the Table 4. The main effect of area is also the most significant effect for the model. The secondarily significant main effects are the effect of NHBF and vessel scale.

For lognormal model analysis based on the data from 1980 to 2011, all main effects and interactions are statistically significant. The selected lognormal model is:

$$\log(CPUE) = \mu + Y + M + A + CT + T\_ALB + T\_BET \\ + Y*A + M*A + M*T\_ALB + M*T\_BET \\ + A*T\_ALB + A*T\_BET + T\_ALB*T\_BET$$

The ANOVA table of the selected lognormal model is shown in the Table 5. The results indicate that the main effect of area is the most significant effect for the model and the secondarily significant main effect is the effect of the CPUE of albacore tuna. The distribution of residuals adequately conforms to the assumption of normal distribution (Fig. 5).

All main effects and interactions are also statistically significant for the delta model analysis based the data from 1980 to 2011. The selected delta model is:

$$
\begin{aligned}
PA = \mu + Y + M + A + CT + T\_ALB + T\_BET \\
+ Y*A + M*A + M*T\_ALB + M*T\_BET \\
+ A*T\_ALB + A*T\_BET + T\_ALB*T\_BET
\end{aligned}
$$

The ANOVA table of the selected delta model is shown in the Table 6. The most explanatory main effect for the mode is also the effect of area and the secondary are the main effect of the CPUE of bigeye tuna.

The area-specific nominal and standardized CPUE are shown in Fig. 6. Generally, trends of standardized CPUEs are close to nominal CPUEs. In addition, the trend of CPUE standardized with environmental effects is almost the same with that standardized without environmental effects. The trends of CPUEs in Area 1 (MONS) and Area 3 (Coastal area) revealed substantial decline trends before early 1990s and increased until later 1990s, while the CPUE in Area 2 (ISSG) continuously increased before 1995. For the time period after 1995, the standardized CPUEs based on different data sets revealed quite similar trends for three areas. The CPUEs slightly increased before 1998 and 2002 for Area 1 and Area 2 respectively, revealed decreasing patterns until 2008, and they sharply increase in recent years. However, the trend of CPUE in Area 3 is quite different from those in Area 1 and Area 2, it obviously increased before 1999 but the continuously decreased thereafter.

Fig. 7 shows the area-aggregated nominal and standardized CPUE of blue marlin in the Indian Ocean. Standardized CPUE generally reveals a trend for five phases: fluctuated before 1986, sharply decreased during 1986-1990 when the catch began increasing; increased gradually during during1991-1999; decrease gradually during 2000-2007; CPUE obviously increased in recent years.

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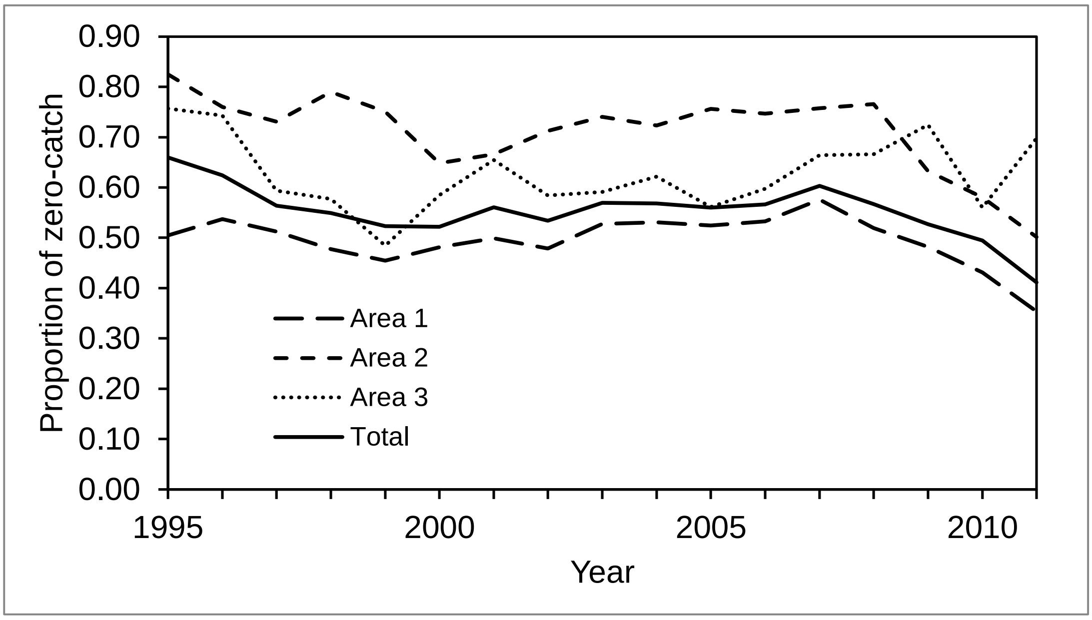


Fig. 1. Annual proportions of operation sets for zero-catch of blue marlin caught by Taiwanese longline fishery for three ecological areas and for entire Indian Ocean.

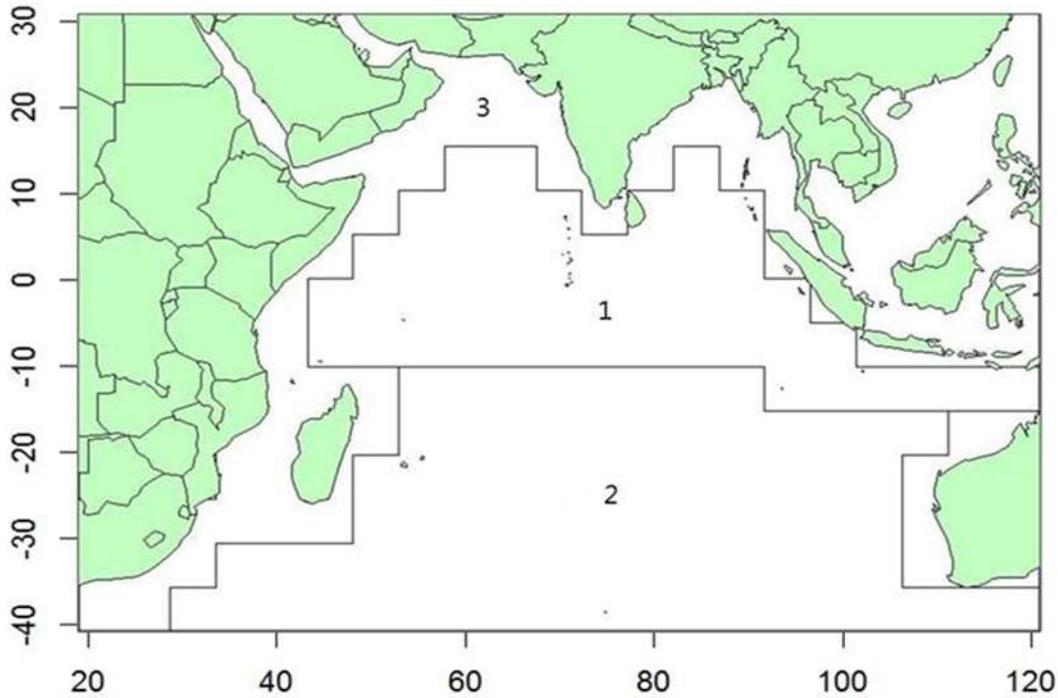


Fig. 2. The definition of ecological geographic areas in the Indian Ocean.

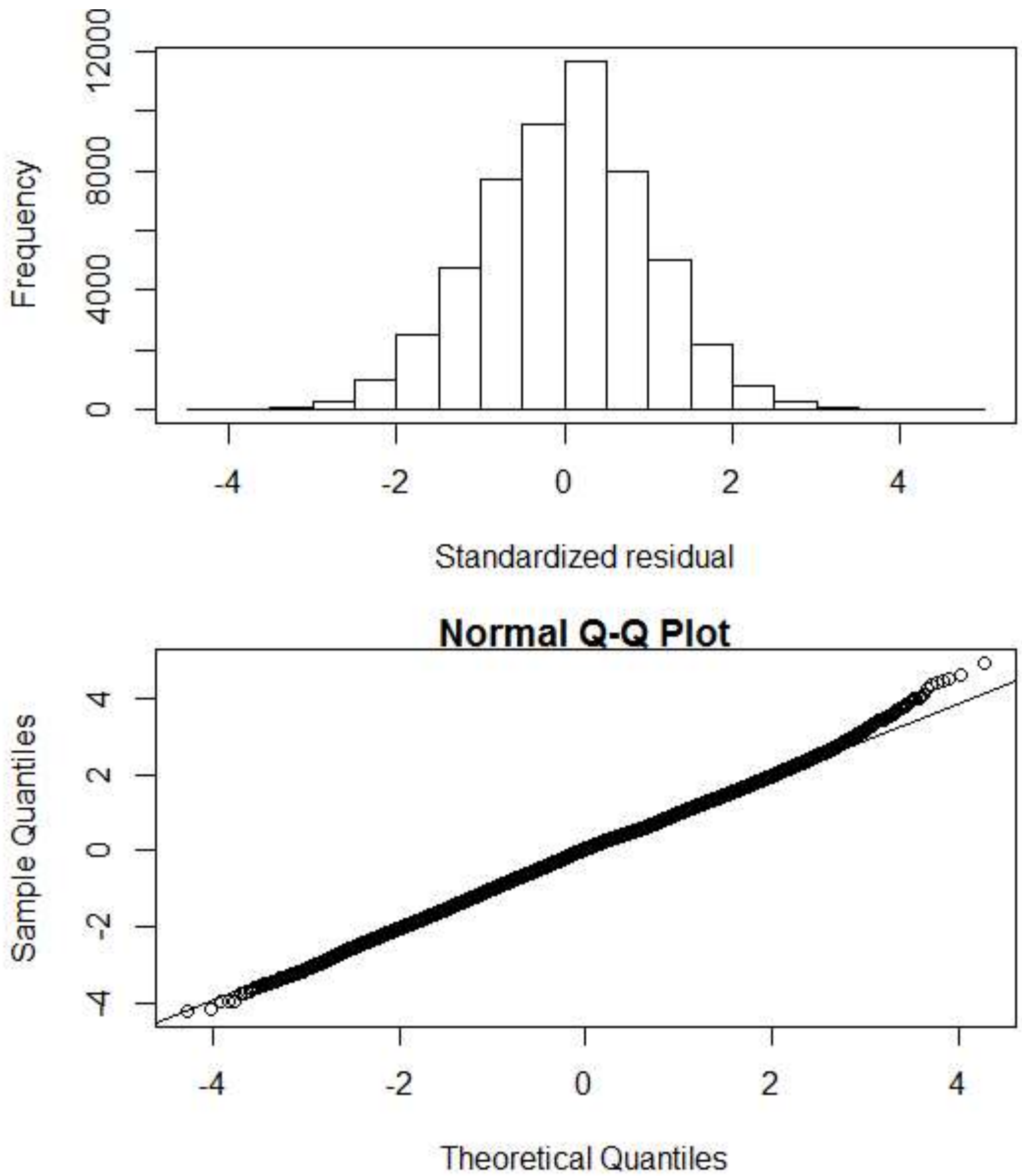


Fig. 3. The distribution and quantile-quantile plot for the residuals obtained from lognormal model based on the data from 1995 to 2011 with environmental effects.

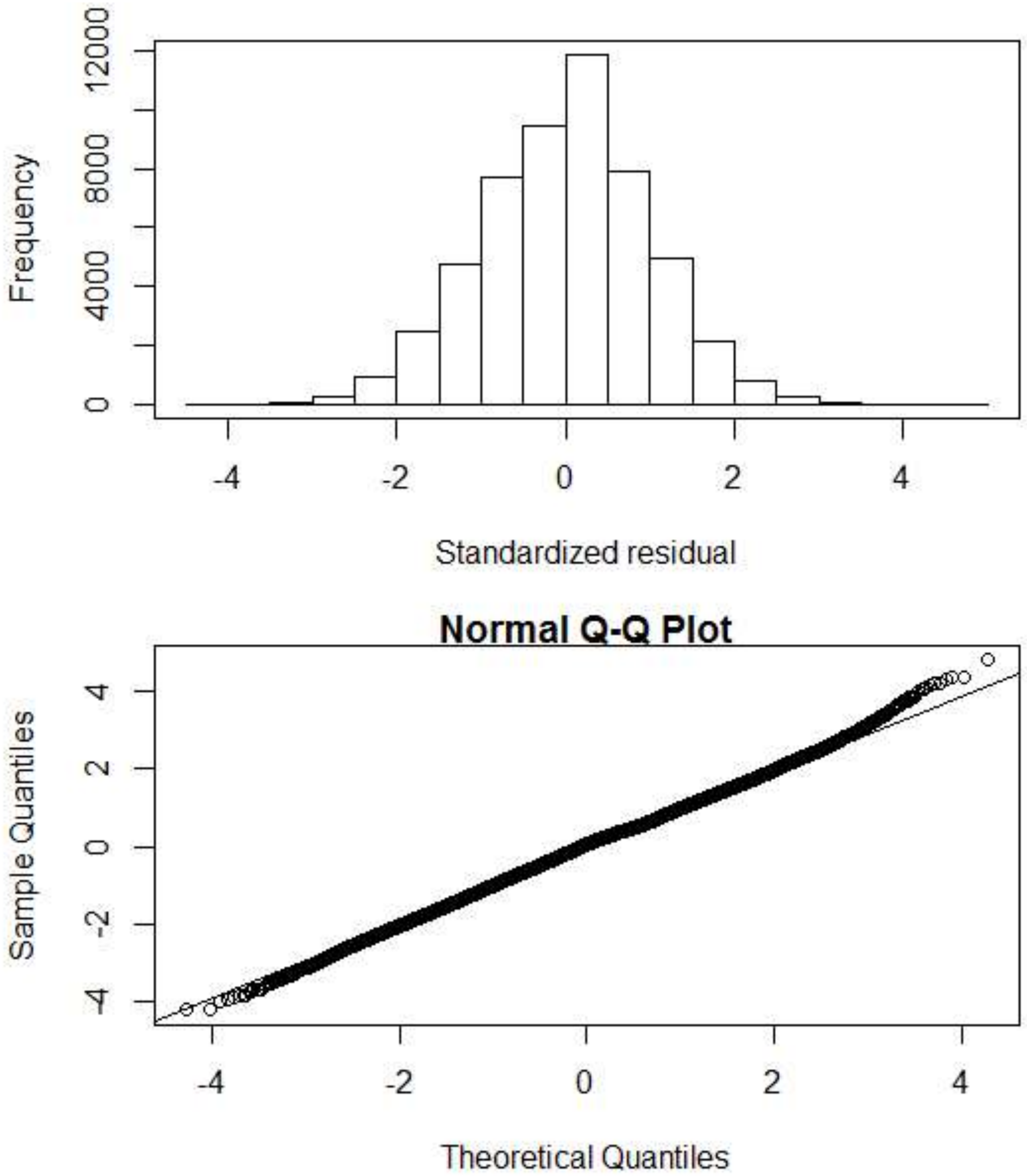


Fig. 4. The distribution and quantile-quantile plot for the residuals obtained from lognormal model based on the data from 1995 to 2011 without environmental effects.

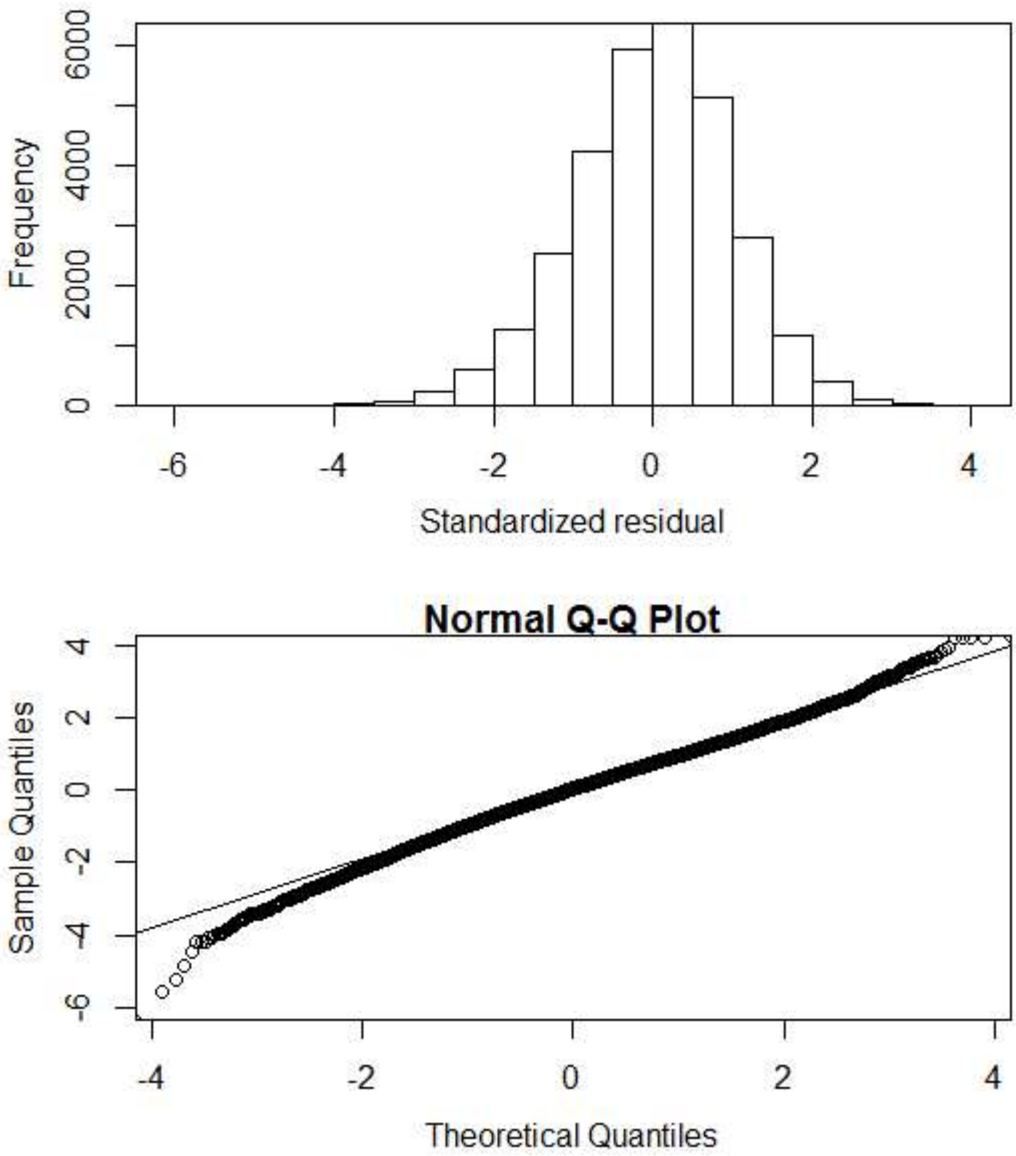


Fig. 5. The distribution and quantile-quantile plot for the residuals obtained from lognormal model based on the data from 1980 to 2011 without environmental effects.

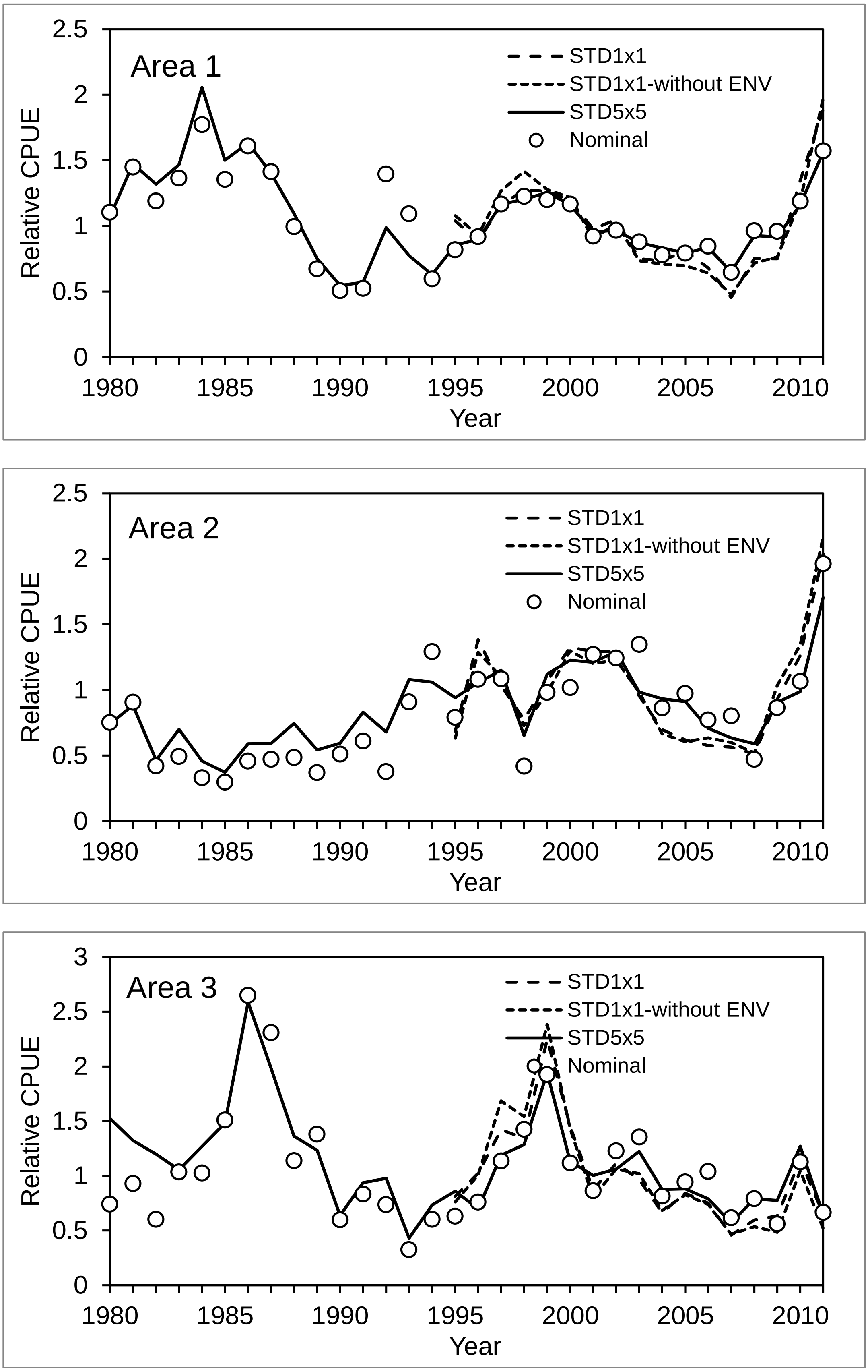


Fig. 6. Area-specific nominal and Standardized CPUE (scaled by average values of 1995 to 2011) of blue marlin caught by Taiwanese longline fleet.

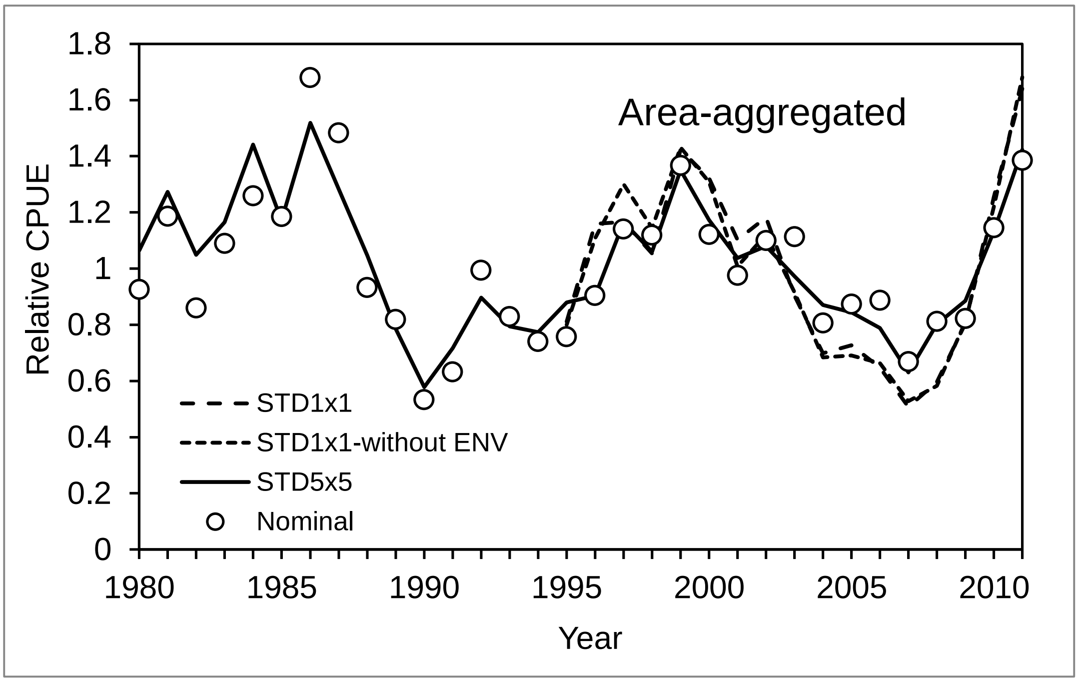


Fig. 7. Area-aggregated nominal and Standardized CPUE (scaled by average values of 1995 to 2011) of blue marlin caught by Taiwanese longline fleet.

Table 1. The ANOVA table for the lognormal model based on the data from 1995 to 2011 with environmental effects.

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 118 | 2993.78 | 25.37 | 35.59 | <.0001 |
| Error | 53647 | 38247.60 | 0.71 | | |
| Corrected Total | 53765 | 41241.38 | | | |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Y | 16 | 1232.31 | 77.02 | 108.03 | <.0001 |
| M | 11 | 374.76 | 34.07 | 47.79 | <.0001 |
| A | 2 | 527.47 | 263.74 | 369.92 | <.0001 |
| CT | 3 | 62.12 | 20.71 | 29.05 | <.0001 |
| NHBF | 2 | 60.25 | 30.13 | 42.26 | <.0001 |
| TD | 1 | 71.40 | 71.40 | 100.14 | <.0001 |
| T55 | 1 | 165.37 | 165.37 | 231.95 | <.0001 |
| TG55 | 1 | 4.56 | 4.56 | 6.40 | 0.0114 |
| SC | 1 | 122.49 | 122.49 | 171.81 | <.0001 |
| Y*A | 32 | 161.11 | 5.03 | 7.06 | <.0001 |
| M*A | 22 | 123.90 | 5.63 | 7.90 | <.0001 |
| M*NHBF | 22 | 65.40 | 2.97 | 4.17 | <.0001 |
| A*NHBF | 4 | 22.63 | 5.66 | 7.93 | <.0001 |

Table 2. The ANOVA table for the delta model based on the data from 1995 to 2011 with environmental effects.

| | Df | Deviance | Resid. Df | Resid. Dev | Pr(>Chi) |
|---|---|---|---|---|---|
| NULL | | | 120189 | 165283 | |
| Y | 16 | 845.57 | 120173 | 164438 | <.0001 |
| M | 11 | 724.42 | 120162 | 163713 | <.0001 |
| A | 2 | 2759.68 | 120160 | 160953 | <.0001 |
| CT | 4 | 816.29 | 120156 | 160137 | <.0001 |
| NHBF | 2 | 691.45 | 120154 | 159446 | <.0001 |
| TD | 1 | 824.81 | 120153 | 158621 | <.0001 |
| T55 | 1 | 1667.5 | 120152 | 156953 | <.0001 |
| TG55 | 1 | 6.41 | 120151 | 156947 | 0.0113 |
| SC | 1 | 44 | 120150 | 156903 | <.0001 |
| Y*A | 32 | 224.44 | 120118 | 156679 | <.0001 |
| M*A | 22 | 262.02 | 120096 | 156417 | <.0001 |
| M*NHBF | 22 | 78.42 | 120074 | 156338 | <.0001 |

Table 3. The ANOVA table for the lognormal model based on the data from 1995 to 2011 without environmental effects.

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 114 | 2703.10 | 23.71 | 33.01 | <.0001 |
| Error | 53651 | 38538.29 | 0.72 | | |
| Corrected Total | 53765 | 41241.38 | | | |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Y | 16 | 1232.31 | 77.02 | 107.22 | <.0001 |
| M | 11 | 374.76 | 34.07 | 47.43 | <.0001 |
| A | 2 | 527.47 | 263.74 | 367.16 | <.0001 |
| CT | 3 | 62.12 | 20.71 | 28.83 | <.0001 |
| NHBF | 2 | 60.25 | 30.13 | 41.94 | <.0001 |
| Y*A | 32 | 162.92 | 5.09 | 7.09 | <.0001 |
| M*A | 22 | 176.18 | 8.01 | 11.15 | <.0001 |
| M*NHBF | 22 | 76.18 | 3.46 | 4.82 | <.0001 |
| A*NHBF | 4 | 30.90 | 7.73 | 10.76 | <.0001 |

Table 4. The ANOVA table for the delta model based on the data from 1995 to 2011without environmental effects.

| | Df | Deviance | Resid. Df | Resid. Dev | Pr(>Chi) |
|---|---|---|---|---|---|
| NULL | | | 120189 | 165283 | |
| Y | 16 | 845.57 | 120173 | 164438 | <.0001 |
| M | 11 | 724.42 | 120162 | 163713 | <.0001 |
| A | 2 | 2759.68 | 120160 | 160953 | <.0001 |
| CT | 4 | 816.29 | 120156 | 160137 | <.0001 |
| NHBF | 2 | 691.45 | 120154 | 159446 | <.0001 |
| Y*A | 32 | 328.38 | 120122 | 159117 | <.0001 |
| M*A | 22 | 835.56 | 120100 | 158282 | <.0001 |
| M*NHBF | 22 | 105.3 | 120078 | 158176 | <.0001 |
| A*NHBF | 4 | 14.55 | 120074 | 158162 | 0.0057 |

Table 5. The ANOVA table for the lognormal model based on the data from 1980 to 2011.

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 194 | 5499.38 | 28.35 | 31.58 | <.0001 |
| Error | 30748 | 27603.53 | 0.90 | | |
| Corrected Total | 30942 | 33102.91 | | | |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Y | 31 | 1031.92 | 33.29 | 37.08 | <.0001 |
| M | 11 | 465.67 | 42.33 | 47.16 | <.0001 |
| A | 2 | 2023.12 | 1011.56 | 1126.79 | <.0001 |
| CT | 6 | 84.25 | 14.04 | 15.64 | <.0001 |
| T_ALB | 2 | 195.49 | 97.74 | 108.88 | <.0001 |
| T_BET | 2 | 14.56 | 7.28 | 8.11 | 0.0003 |
| Y*A | 62 | 571.45 | 9.22 | 10.27 | <.0001 |
| M*A | 22 | 541.06 | 24.59 | 27.40 | <.0001 |
| M*T_ALB | 22 | 131.26 | 5.97 | 6.65 | <.0001 |
| M*T_BET | 22 | 44.46 | 2.02 | 2.25 | 0.0007 |
| A*T_ALB | 4 | 93.32 | 23.33 | 25.99 | <.0001 |
| A*T_BET | 4 | 266.49 | 66.62 | 74.21 | <.0001 |
| T_ALB*T_BET | 4 | 36.32 | 9.08 | 10.11 | <.0001 |

Table 6. The ANOVA table for the delta model based on the data from 1980 to 2011.

| | Df | Deviance | Resid. Df | Resid. Dev | Pr(>Chi) |
|---|---|---|---|---|---|
| NULL | | | 55873 | 76810 | |
| Y | 31 | 503.9 | 55842 | 76306 | < .0001 |
| M | 11 | 1351.7 | 55831 | 74954 | < .0001 |
| A | 2 | 6862 | 55829 | 68092 | < .0001 |
| CT | 6 | 390 | 55823 | 67702 | < .0001 |
| T_ALB | 2 | 400.1 | 55821 | 67302 | < .0001 |
| T_BET | 2 | 1492.7 | 55819 | 65809 | < .0001 |
| Y:A | 62 | 684.3 | 55757 | 65125 | < .0001 |
| M:A | 22 | 777.8 | 55735 | 64347 | < .0001 |
| M:T_ALB | 22 | 219 | 55713 | 64128 | < .0001 |
| M:T_BET | 22 | 66.7 | 55691 | 64061 | < .0001 |
| A:T_ALB | 4 | 41.9 | 55687 | 64019 | < .0001 |
| A:T_BET | 4 | 17.1 | 55683 | 64002 | 0.0018 |